# Japanese Activities for BIOMASS

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## BIOMASS 計画における日本の活動

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**要旨**: 南極海洋生物資源管理の基礎として，南極海の海洋生態系の構造と動的機能をより深く理解することを目的とした BIOMASS 計画は，1977 年から 10 カ年計画として実施された国際共同研究であった．1991 年 9 月，ドイツ国，ブレーメーハーフェンで開催された研究成果総括のための "BIOMASS Colloquium" をもって，すべての活動を終結した．かねて南極海の生物資源，とくにナンキョクオキアミの利用の可能性について関心を持っていたわが国の研究者，研究機関は BIOMASS 計画に積極的に参加した．BIOMASS 計画では，1980–81 年に第 1 回国際共同多船観測 (FIBEX) 計画を組み，ナンキョクオキアミ現存量のいっせい調査を行った．わが国からは，海鷹丸，白鳳丸，開洋丸が参加した．また，第 2 回国際共同多船観測 (SIBEX) が，1983–84，1984–85 年の 2 期に分けて行われ，第 1 期には海鷹丸，開洋丸が，第 2 期には開洋丸が航海を行った．第 2 回多船観測では，調査・研究の力点は，生態系全般の研究に移行した．国際多船観測とは別に，海鷹丸，開洋丸はそれぞれ独自の調査航海を行っているが，いずれも南極海の海洋生態系の解明を目的としたものであり，BIOMASS の一環と見ることができる．日本南極地域観測隊は，BIOMASS 計画に合わせて，船上における定常観測を拡充すると共に，定着氷縁，昭和基地周辺の定着氷域での研究を行った．これらの研究は，観測・研究船の夏期開水域での研究成果と共に，海氷域における冬期を含めた生態系の構造と機能についての基本的情報を提供した．これらの研究を通して，わが国の南極海海洋生態系に対する理解は格段に深まったと考えられる．これまでに発表された論文，報告の数は，200 編を超える．

***Abstract***: Japanese scientists have been interested in the utilization of Antarctic krill as a potential resource of protein for mankind. Thus, the objectives of BIOMASS which aimed at gaining the knowledge of Antarctic marine ecosystems for the management of Antarctic marine living resources were accepted by Japanese scientists and supported by the Japanese government. In succession to the pre-BIOMASS activities, Japanese vessels, UMITAKA MARU III, KAIYO MARU and HAKUHO MARU conducted cruises to participate in FIBEX and SIBEX. Furthermore, two additional cruises were undertaken by the KAIYO MARU as an extension of BIOMASS. The Japanese Antarctic Research Expedition contributed to BIOMASS with the observations onboard the FUJI and SHIRASE and shore-based research at Syowa Station. The UMITAKA MARU III and the HAKUHO MARU investigated primary production, abundance and distribution of phyto-

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南極資料, Vol. 35, No. 3, 402–433, 1991
Nankyoku Shiryô (Antarctic Record), Vol. 35, No. 3, 402–433, 1991

plankton, zooplankton and micronekton and organic particles with oceanographic conditions in the Southern Ocean south of Australia. The KAIYO MARU surveyed physical, chemical and biological conditions along several meridional lines and in grids in the Indian and Atlantic sectors of the Southern Ocean. Stress was put on the acoustic survey of the krill abundance and distribution for the estimation of its biomass. Accordingly studies of target strength were undertaken. The Japanese Antarctic Research Expedition provided physical, chemical and biological data obtained in the ice-covered waters along with those in open seas. Summer data in the fast ice edge zone and year-round data at Syowa Station complemented the Japanese BIOMASS data file, most of which were formed with onboard summer research in the open water. BIOMASS encouraged Japanese marine scientists to pay their attention to the Southern Ocean. Their experience in the Southern Ocean has become a foundation in promoting research relating to the global change of environment, which focuses attention as one of the most important research themes at present.

## 1. Introduction

### *1.1. Background*

Interest in the Antarctic krill, *Euphausia superba* as a potential protein resource of mankind, had increased in the early 1970's. In Japan the possibility of utilization of the krill had been discussed among scientists in the 1960's. Concurrently it had been considered that the utilization of the krill should be made carefully because the krill seemed to play a key role in the Antarctic marine ecosystems. Accordingly, Japanese scientists who took interest in the Antarctic research positively responded to the Biological Investigations of Marine Antarctic Systems and Stocks (BIOMASS) program of the Scientific Committee on Antarctic Research (SCAR), when it was proposed in 1975. The principal objective of BIOMASS program was *to gain a deeper understanding of the structure and dynamic functioning of the Antarctic marine ecosystem as a basis for the future management of potential living resources.* This intention agreed with the direction of research conceived by most of Japanese scientists who were interested in the Antarctic biology.

### *1.2. Activities prior to BIOMASS*

Before the commencement of BIOMASS, Japanese contributions to the Antarctic marine biology were made through the research work in relation to the whaling, the observations by Japanese Antarctic Research Expedition (JARE) (since 1957) and the investigations carried out onboard the UMITAKA MARU II (1956–57, 1961–62, 1964–65 and 1966–67) and the HAKUHO MARU (1973–74). Since the 1972–73 season Japan Marine Fishery Resources Center (JAMARC) had conducted pilot studies of krill utilization including survey of the distribution and abundance of the krill. Antarctic cruises to study ecology and biology of the krill as a future food resource were undertaken by Tokyo University of Fisheries (UMITAKA MARU III) in 1977–78 and by Fisheries Agency (KAIYO MARU) in 1979–80.

### *1.3. Organizations*

In order to participate in BIOMASS, the support of research organizations which had their research vessels, and the involvement of scientists who were interested in the

environment, living organisms and ecosystems in the Southern Ocean were considered to be essential. The Japanese national committee for SCAR, that is Committee on Antarctic Research of the Japanese Science Council had formal responsibility to both national and international affairs in relation to the promotion of BIOMASS and it was intended to strengthen its power by setting up a subcommittee for BIOMASS. The subcommittee consisted of marine biologists, fisheries scientists and physical and chemical oceanographers. At the same time, a group of scientists for promoting scientific research in relation to BIOMASS was organized to provide a forum to scoop views, ideas and information of scientists who took interest in research themes related to BIOMASS.

In parallel with this, governmental arrangements were made. The onboard programs planned by Tokyo University of Fisheries (UMITAKA MARU III), Ocean Research Institute of the University of Tokyo (HAKUHO MARU), Fisheries Agency (KAIYO MARU) and National Institute of Polar Research (FUJI and SHIRASE) for First International BIOMASS Experiment (FIBEX) and Second International BIOMASS Experiment Phase I and II (SIBEX-I and SIBEX-II) were coordinated through the consideration of the Special Committee for Antarctic Marine Living Resources, National Institute of Polar Research (NIPR). The coordinated cruise plans were endorsed by the Headquarters of Japanese Antarctic Research Expedition as part of the national programs of Japanese Antarctic research.

### *1.4. Participation*

The highlight of BIOMASS was FIBEX in 1980–81, SIBEX-I in 1983–84, and SIBEX-II in 1984–85. In this regard, as summarized below, the UMITAKA MARU III and the KAIYO MARU took part in FIBEX, the UMITAKA MARU III, the KAIYO MARU and the HAKUHO MARU participated in SIBEX-I and the KAIYO MARU did in SIBEX-II. The research at Syowa Station and the observation onboard the FUJI (till 1982–83 summer) and the SHIRASE (since 1983–84 summer) by JARE were considered as an important part of Japanese contributions to BIOMASS. The JARE research was expected to be a source of biological information in the ice-covered seas into which other Japanese research vessels than the FUJI and the SHIRASE cannot penetrate.

After ceasing the international BIOMASS fieldwork the KAIYO MARU carried out cruises two times in 1987–88 and 1990–91 to obtain basic data for the assessment and future management of krill resource, taking into account the BIOMASS objective and the intention of Commission for Conservation of Antarctic Marine Living Resources (CCAMLR), and the Shirase is continuing onboard observations on the physical and chemical characters and the concentration of chlorophyll *a* in the surface water along the cruise track.

### *1.5. Meetings*

A meeting of the Group of Specialists on Antarctic Ecosystems and their Living Resources was held in Nikko in May to June 1982. The research plans for SIBEX, the handling of BIOMASS data and other topics were discussed. Just before this meeting, the BIOMASS colloquium was convened at National Institute of Polar Research, Tokyo. The presentation and discussion of the scientific results of BIOMASS

and other studies done in the Southern Ocean were made. The proceedings of the colloquium was published as Memoirs of National Institute of Polar Research, Special Issue, No. 27 in 1983. Also a meeting of the Technical Group on Data, Statistics and Resource Evaluation and a SCOR/SCAR workshop on the Enhancement of Interaction between Physical, Chemical and Biological Oceanographers were held at NIPR.

Ad hoc Group on Squid Biology, a subsidiary body of Group of Specialists on Antarctic Ecosystems and their Living Resources had a meeting at Ocean Research Institute, the University of Tokyo in September 1983.

### *1.6. Future*

A considerable amount of data and samples were collected through BIOMASS activities. These data on the Antarctic marine ecosystems are essential to make the management plan of Antarctic marine living resources. However, there still remained such gaps in our knowledge on Antarctic marine ecosystem as the krill biomass and squid biology. Researches aiming at the management of marine living resources should be conducted in conjunction with the CCAMLR activities.

The information acquired through BIOMASS is considered useful baseline data for the monitoring of variation of Antarctic marine ecosystems in relation to global change of natural environment. In this regard, ongoing and planned Antarctic researches should be made taking into account the experience in BIOMASS.

This report contains the summaries of scientific work carried out onboard the vessels and at the station as the Japanese activities in the international BIOMASS program with the simplified cruise tracks of vessels (Appendix 1) and the lists of scientific results in relation to BIOMASS published before mid-1991 (Appendix 2).

The outline of this report was presented at the poster session of the BIOMASS Colloquium held on September 18–20, 1991 at Bremerhaven, Germany.

## 2. Field Activities

### *2.1. Tokyo University of Fisheries (UMITAKA MARU III)*

In response to the BIOMASS, cruises of T/S UMITAKA MARU III, Tokyo University of Fisheries were conducted three times during the period from 1977 to 1984 in the Australian sector of the Southern Ocean.

#### 2.1.1. Pre-FIBEX

The first cruise was done in the 1977–78 season. The UMITAKA MARU III left Tokyo on November 2, 1977 and returned on February 27, 1978, spending 49 days for scientific work in the Southern Ocean and its vicinity. The objectives of this cruise were to carry out; 1. Studies on the distribution of the krill by means of a fish pump and a midwater trawl (net), both of which were newly designed for krill sampling, 2. Acquisition of basic information on the distribution and abundance of the krill with a fish finder, 3. Preliminary laboratory experiments on the krill physiology with the fresh and sound individuals of the krill caught with the pump and trawl net, and 4. The physical, chemical and biological observations on oceanographic conditions along the cruise track.

Oceanographic observations and biological samplings were carried out along the longitudes of 120°E, 150°E and 167°E south of 50°S and in the two areas sur-

rounded with 63°S and 65°S latitudes and 120°E and 132°E longitudes and 64°S and 66°S latitudes and 150°E and 160°E longitudes.

The krill sampled with the fish pump on January 25, 1978 were provided for the onboard experiments of the filtering rate of diet under the different concentrations of food particles and oxygen consumption at different temperatures. Part of the krill, which were reared in the laboratory at Tokyo University of Fisheries for more than 265 days following the onboard culture, were used for the measurements of growth increment and moulting frequency. The growth increment in body length was estimated as 12.92 mm $y^{-1}$ and the moulting occurred once per 16–26 days.

A tentative estimation of krill abundance in the Antarctic Ocean was made with a model combining the krill patch distribution and the krill biomass in the observed patches. The krill abundance was estimated as 3.6 hundred million to 13.7 hundred million tons. For the measurement of the krill biomass a fish finder (FURUNO FWGT-23, 200 kHz, 5 kW) was applied. Investigations on the vertical distribution and migration of the krill in relation to photic conditions were also made with the fish finder data.

2.1.2. FIBEX

The second cruise was undertaken in the 1980–81 season in the Australian sector of the Southern Ocean. Since this cruise was conducted to participate in the FIBEX, the stress in research was put on the ecological investigations of marine Antarctic ecosystems. Investigations on the krill biology were continued following the first cruise in 1977–78. The physical, chemical and biological observations of oceanographic conditions along cruise track were routinely carried out. Special efforts were made to acquire ecological information on phytoplankton, zooplankton, organic particles, seabirds and whales. In addition, the geographical distribution of chlorinated hydrocarbons was studied along the cruise track.

The UMITAKA MARU III left Tokyo on November 11, 1980 and returned on March 11, 1981, after spending 50 days for scientific work in the Southern Ocean and its adjacent areas.

Along 125°E from 45°S to 65°S, 12 CTD and 59 XBT stations were occupied. XBT observations were made at 17 stations on the line between 50°19′S, 151°47′E and 57°25′S, 154°E and 11 CTD and 19 XBT observations were carried out along the 160°E meridional line between 65°S and 55°S. Based on the data obtained, the polar front (56°S in both 125°E and 160°E) and the Antarctic divergence zone (64°S in 125°E and 62°S in 160°E) were identified. The chlorophyll *a* concentration in the surface water was 0.118–0.385 mg $m^{-3}$. Diurnal fluctuation of *in vivo* fluorescence in the surface layer was observed. Subsurface chlorophyll *a* maximum was observed in the layers from 50 to 125 m depth, which were also temperature minimum layers at the stations occupied south of the polar front. The integrated amount of chlorophyll *a* in the water above 200 m depth layer was 12.48–50.96 mg $m^{-2}$. The phytoplankton communities dominated by diatoms and dinoflagellates were investigated and some detailed taxonomical information was acquired.

The samplings of macrozooplankton and micronekton were made. Remarkable components in zooplankton and micronekton along 125°E and 160°E north of the polar front were copepods, chaetognaths and amphipods but along 160°E south of the

polar front copepods and euphausiids.

Vertical flux and horizontal and vertical distributions of particulate organic matter and also dissolved organic matter were investigated in relation to the physical oceanographic conditions. The results indicated a close relationship between organic particles and regional movement of water, but further investigations are required to reach conclusions. As for the nutrient cycle in the marine Antarctic ecosystem, the concentration and composition of fatty acids in the particulate matter were investigated at a station near 64°35′S, 125°E.

Following the first cruise, the onboard laboratory experiments showed that filtering rate and feeding rate of the krill were high in the water which contained much food. Respiration rate of 3.31–139.97 $\mu l\ O_2\ Ind^{-1}\ h^{-1}$ was recorded for the krill of 6.1–385.4 mg in dry weight. Sighting of seabirds and whales was carried out along the cruise track.

2.1.3. SIBEX-I

The third cruise was conducted in the 1983–84 season in the Australian sector of the Southern Ocean. This cruise was devoted to the SIBEX-I. Thus investigations on the structure and function of marine Antarctic ecosystems and on the krill biology were carried out. To make effective data acquisition in the research area, the cruise schedules of the UMITAKA MARU III and the HAKUHO MARU, Ocean Research Institute of the University of Tokyo, were coordinated in advance.

The UMITAKA MARU III departed from Tokyo on November 22, 1983 and returned on March 14, 1984, after spending 41 days in the Southern Ocean and its neighboring waters. Oceanographic observations were carried out at 12 stations along 116°E and 15 stations in the 118°E, 120°E and 122°E between 60°S and 65°S. Further observations were made at 10 stations along 150°E and 4 stations around 65°S, 147.5°E. CTD and XBT observations were carried out at 42 and 152 stations, respectively. Samplings of plankton and micronekton, primary productivity measurements with the *in situ* $^{13}C$ method and acoustic survey of the krill were carried out at selected stations in addition to the CTD observation. Research efforts were concentrated in the two areas around 62°S, 120°E and 63°S, 150°E. A sediment trap moored at about 61°30′S, 150°E by the HAKUHO MARU on December 25, 1983 was recovered on February 5, 1984.

Subtropical convergence, subantarctic front, Antarctic front and Antarctic divergence were identified at 40°S, 49–50°S, 55–56°S and 63–64°S along 116°E and 47°S, 55°S, 56–58°S and 63–64°S along 150°E. The latitudinal variation of nutrient salts was observed. In general, concentrations of $PO_4$, $NO_2$ and $NO_3$ increased stepwise at the fronts towards south and that of $SiO_3$ became high beyond the Antarctic front. The mean chlorophyll *a* concentrations and integrated chlorophyll *a* contents above 200 m depth in the water along 116°E and 150°E were 0.226–0.399 mg $m^{-3}$ and 0.150–0.245 mg $m^{-3}$ and 26.51–52.28 mg $m^{-2}$ and 17.40–44.60 mg $m^{-2}$, respectively. Primary productivity measured at 65°S, 116°20′E and 65°S, 150°E was 29.22 mgC $m^{-2}\ h^{-1}$ and 5.84 mgC $m^{-2}\ h^{-1}$. It was also clarified that the major part of chlorophyll *a* owed to the nannoplankton of 3–20 $\mu$m in the Southern Ocean. The latitudinal distribution of protists was investigated in relation to the fronts. Amoeba and colorless dinoflagellates were common and predominant constituents in heterotrophs

in the Southern Ocean.

The mean concentration of particulate organic carbon and that of particulate nitrogen were 59.7–118 $\mu$gC $l^{-1}$ and 8.85–16.6 $\mu$gN $l^{-1}$ in the surface water and decreased with depth to ranges of 16.1–54.1 $\mu$gC $l^{-1}$ and 1.48–3.44 $\mu$gN $l^{-1}$.

Composition of amino acid, carbohydrate and lipid in the particulate organic carbon was analyzed. Total amount of the three components occupied 63.8–88.3% of particulate organic carbon in the surface and decreased with depth. In general, the proportion of amino acid and lipid to the particulate organic carbon increased inversely with water temperature. Proportion of lipid was high in the subsurface temperature minimum layer and that of amino acid was high in the surface layer.

The abundance of krill estimated with the acoustic survey was 0.0287 g $m^{-3}$ and 0.0712 g $m^{-3}$ in the two surveyed areas, and these values were about four times that in the FIBEX cruise carried out by the UMITAKA MARU III in almost the same area.

As for the feeding of krill, results of ingestion experiments indicated that in the concentration of food particles in the ambient waters, individuals larger than 8.16 mg in dry weight could not catch food to satisfy their minimum requirement for nourishment and that might have opportunities to take sufficient food sometime during summer. An analysis of lipid and amino acid composition of fecal pellet of krill and possible food plankters showed that small krill fed on diatoms but larger one took both diatoms and choanoflagellates. Sighting of seabirds and whales was conducted to accumulate basic information on the ecosystem structure following the FIBEX.

### 2.2. *Fisheries Agency (KAIYO MARU)*

BIOMASS and BIOMASS related research cruises which were performed by the KAIYO MARU, Fisheries Agency of Japan were carried out six times during the period from the 1979–80 season to the 1990–91 season. Prior to the commencement of cruises of the KAIYO MARU, in 1972–73 a feasibility study for the utilization of the Antarctic krill as a future resource of protein for mankind was started by JAMARC. Following this pilot study, commercial operations for the krill began in 1973–74 and have been continued until now. Since Fisheries Agency of Japan intended to rationally utilize the krill, it emphasized the need to collect basic data on the environment and ecosystem of fishing ground to avoid harmful effects of fisheries activity to the natural environment and ecosystems of the Antarctic Ocean, as well as the necessity for obtaining basic information on the biology of the krill to prevent its depletion.

#### 2.2.1. Pre-FIBEX

The first cruise was done in the 1979–80 season. The objectives of this cruise were the acquisition of basic information on the environment and ecosystems in the waters off the western coast of Wilks Land, the estimation of the krill abundance and the examination of biological parameters of the krill. The KAIYO MARU departed from Tokyo on December 12, 1979 and returned on March 8, 1980. Research work was done for 37 days in the Southern Ocean. A region encircled by 100°E and 120°E and 61°S and 65°S was selected for the intensive study. Along five meridional lines occupied at 5° intervals from 100°E to 120°E physical, chemical and biological observations were routinely carried out at intervals of 20′ latitude. Plankton samplings were made at selected stations out of the routine stations. In addition, intensive plankton samplings with oceanographic observations were done in the areas of 65°S, 115°E

and 65°S, 120°E, where abundance of the krill was high. Hydroacoustic survey was done continuously along the cruise track of the ship. Observations of the krill reared on board was made. Sighting of seabirds and whales was made along the cruise track.

Frontal zones, subtropical convergence, Australasian subantarctic front and Antarctic convergence were observed at 40°06′S, 111°28′E, 47°–49°S, 110°E and 55°42′S, 105°20′E in the southbound cruise and 44°07′S, 140°42′E, 51°–52°S, 135°E and 58°47′S, 129°22′E in the northbound cruise. A general eastward current was observed in the study area, in which there were regional current systems. The cyclonic and anticyclonic eddies were observed in the area enclosed with latitudinal lines of 62°S and 62°30′S and longitudinal lines of 105°E and 110°E. A strong meandering of eastward flow which seemed to be induced by the bottom topography was seen south of 63°S. The krill abundance was high beyond 64°S. The krill density estimated with the net sampling was 1–40 g $m^{-3}$. It seemed that there was a close relationship between the krill abundance and high concentration of chlorophyll *a*. Breeding behavior of the krill was observed in an onboard aqualium. The number of eggs, frequency of egg laying and the development of laid eggs were examined. The eggs developed to the metanauplius stage one month after the egg liberation. Sighting of seabirds and whales was done to accumulate basic information on their distribution.

2.2.2. FIBEX

The second cruise of the KAIYO MARU was conducted to participate in the International Indian Program of FIBEX. The main objectives of this cruise were to continue oceanographic research of the marine Antarctic environment and ecosystems and to develop acoustic survey of the krill distribution and abundance in the waters including fishing grounds of Japanese fisheries fleet. The KAIYO MARU left Tokyo on November 11, 1980 and returned on March 18, 1981. Research work was done for 50 days in the Southern Ocean. The cruise of the KAIYO MARU in the Southern Ocean consisted of two legs. The observations of the first leg were mainly made in the area between 60°E and 85°E south of 61°S and those of the second leg in the area between 30°E and 55°E south of 63°S. Six north-south lines at 5° intervals were set at each of two research areas and physical, chemical and biological observations were carried out along the transects. The distribution of phytoplankton, zooplankton and particulate matter was observed in relation to the physical and chemical oceanographic conditions. Acoustic survey of the krill was also carried out along the cruise track. Abundance of the krill was high in the southern part of survey areas, which were within 200 km from the pack ice edge. Major zooplankters other than the krill were Medusae, Thaliacea and Pteropoda in these areas. Intercalibration of the scientific echo sounder and comparison of sampling efficiency of two trawl nets equipped on the Australian research vessel NELLA DAN and the KAIYO MARU were undertaken. Sighting of seabirds and whales was made along the cruise track.

2.2.3. SIBEX-I

The third cruise was conducted to participate in SIBEX-I. The objectives of research set up in succession to the second cruise were to collect basic data on the oceanographic conditions and marine ecosystems of the Southern Ocean and to make acoustic survey of the krill. The research area, however, was selected between 65°E

and 75°E south of 61°S off Prydz Bay, taking into account the scheme negotiated by the Indian Sector group of SIBEX. Five meridional lines at 2°30′ intervals were set for the oceanographic observations and biological samplings. The first observation was carried out along these lines between 61°S and 64°S in the period of December 4 to 25, 1983. The south end of the observation sites was limited with the pack ice edge. The second observation was made along the southern part of five lines previously settled. In general, observations were done between 63°S and 69°S because of the retreat of ice edge.

The physical structure of water mass in the research area was observed. The distribution of nutrients, chlorophyll *a* with phaeopigments and dissolved oxygen contents were measured in conjunction to the physical conditions of sea water. Chlorophyll *a* concentration was high in a subsurface layer which coincided with the temperature minimum layer. It appeared that this high chlorophyll layer extended to south with the retreat of ice edge. Target strength of the krill measured *in situ* was $-66.2$ dB 1 $g^{-1}$ with an echo integrator, FQ-50 with a frequency of 200 kHz. The krill biomass was estimated acoustically as 5,490,000 t over the second survey area with higher density in the southern part of research area on both occasions. Size composition and morphological parameters of the krill were investigated. Sighting of seabirds and whales was made along the cruise track.

2.2.4. SIBEX-II

The fourth cruise of the KAIYO MARU was conducted to participate in SIBEX-II. Most of proposed research articles followed those of the previous cruise to continue the efforts in obtaining basic data on the oceanographic conditions and ecosystems of the Southern Ocean and in carrying out acoustic survey of the krill abundance. The KAIYO MARU left Tokyo on October 9, 1984 and returned on March 10, 1985. The research cruise in the Southern Ocean consisted of two legs. Lines along the 90°W longitude and along the west coast of the Antarctic Peninsula and a transect crossing the Drake Passage were covered in the first leg from November 27 to December 17, 1984. Lines along 30°W in the eastern part of the Scotia Sea, off the Prince Astrid Coast and along the 12°E longitude were investigated in the second leg from January 2 to 22, 1985. Physical, chemical and biological observations were carried out along the cruise track. Basic data on the horizontal and vertical distribution of the biomass of phytoplankton, zooplankton and the krill were collected. The target strength of the krill measured *in situ* was $-57.6$ dB 1 $g^{-1}$. Average krill density was estimated acoustically as 11.5 g $m^{-2}$ throughout the track lines in the survey region. Abundant krill were observed in the north of the South Shetland Islands and in the west of the South Sandwitch Islands. Sighting of seabirds and whales was carried out along the cruise track.

2.2.5. Post-SIBEX

The fifth cruise was conducted to further efforts on the estimation of the krill biomass to acquire basic data for the management of Antarctic marine living resources, taking into account the action of CCAMLR. The proposed research articles were composed of the investigations for the determination of target strength of the krill with the echo integrator installed on board the KAIYO MARU, the acoustic survey of the krill distribution and abundance and physical, chemical and biological investiga-

tions of oceanographic conditions in relation to the krill distribution. For the krill biomass studies, cooperative operations with a USA/Poland Research Vessel, PROFESSOR SIEDLECKI and a Japanese trawler, ASO MARU were undertaken.

The KAIYO MARU left Tokyo on October 28, 1987 and returned on March 16, 1988. The research cruises in the Southern Ocean consisted of two legs. A transect between 56°S, 70°W and 62°S, 55°W, crossing the Drake Passage and three lines along 55°W (57°–62°S), 50°W (56°–62°S) and 45°W (50°–62°S) were covered with the first leg from December 16 to 28, 1987. The cruise of the second leg was made first in a line along 60°W south of 57°S. Successively the cooperative research for the determination of target strength of the krill with the ASO MARU was done at about 62°S, 60°23′W, north of Livingston Island, South Shetland Islands on January 17 to 20, 1988. Intercalibration of the echo integrator and net sampling with PROFESSOR SIEDLECKI was done at about 61°S, 56°W, north of Elephant Island on January 23 and 24, 1988.

According to both the result of acoustic survey with the echo integrator, FURUNO FQ-50 and the catch amount of the krill by the ASO MARU, calculated target strength of 1 g in wet weight of the krill was −66.1 dB. Furthermore, target strength of the krill measured twice *in situ* was −60.9 dB 1 $g^{-1}$. The krill biomass estimated with the echo integrator was 23,850,000 t in the waters south of 57°S in the survey area and 600,000 t in the cooperative survey area with a trawler (30′ latitude × 1° longitude). As for the krill density, results of the sampling with a KYMT net gave a figure of 84 g in wet weight 1000 $m^{-3}$. The northern limit of the krill distribution shifted northward as one goes eastward.

The structure of water mass and the position and oceanographic conditions of frontal zones were elucidated through physical and chemical oceanographic observations. Close relationship of high chlorophyll concentration with high contents of dissolved oxygen and low contents of phosphate-P and nitrate-N was generally observed. This indicated high primary productivity in this water. Sighting of seabirds and whales was carried out along the cruise track.

2.2.6. Post-BIOMASS

The sixth cruise was conducted to continue research on the biology of the krill to contribute to the management of the krill and other Antarctic marine living resources. Research programs were composed of the acoustic survey of the krill distribution and abundance, the observation of interaction between the krill and its predators and the measurements of biological parameters of the krill in relation to environmental conditions. The physical, chemical and biological observations of oceanographic conditions and the sighting observations of seabirds and whales were carried out. The investigation on the interaction between the krill and predators was undertaken in cooperation with the National Oceanic and Atmospheric Administration (NOAA), USA.

The KAIYO MARU left Tokyo on November 1, 1990 and returned on March 22, 1991. The research cruise in the Southern Ocean consisted of two legs. In the first leg oceanographic observations were carried out in the vicinity of the South Shetland Islands including Bransfield Strait, but in the second leg observations were concentrated in the waters north of the South Shetland Islands. Intensive acoustic survey of the

krill was done in a limited area north of Livingston Island two times in late December 1990 and in late January to early February 1991. It was observed that the krill density in the second leg was about 3, 4 times higher than that in the first leg. Feeding behavior of such krill predators as chinstrap penguin, macaloni penguin and Antarctic fur seal was investigated at Seal Island and its vicinity. Diving sequence and position of individual predator were automatically recorded. The species composition of stomach contents of predators and the distribution and abundance of the krill in their foraging field were investigated. Results will contribute to the analysis of function of ecosystems. Reduction of the data and processing of the samples obtained in the sixth cruise are in progress.

*2.3. Ocean Research Institute, University of Tokyo (HAKUHO MARU)*

The KH-83-4 cruise of the HAKUHO MARU formed the SIBEX-I actively in the Pacific sector of the Antarctic along with another ship, UMITAKA MARU of the Tokyo University of Fisheries. The studies carried out on the HAKUHO MARU included those on the Antarctic pelagic ecosystem and its dynamics especially on krill-dominant waters.

The HAKUHO MARU operated mostly in the southern oceans of Australia including the Antarctic Ocean. Scientific research was carried out mainly along 150°E from December 11, 1983 to January 2, 1984 and along 115°E in the period of January 18 to 31, 1984. Besides 30 scientists from 9 organizations, one formal observer (from the People's Republic of China) to the Japanese Antarctic operation joined the cruise.

The following research items were investigated: 1. Studies on distribution, specific compositions and production of plankton and micronekton, 2. Studies on the grazing activity of zooplankton such as copepods, euphausiids and thaliaceans on phytoplankton, 3. Ecological studies on marine bacteria, 4. Studies on the characteristics of biological activities under low temperature and long daylight conditions, 5. Assessments of the krill abundance with a fish finder, 6. Measurements of gravity and magnetics, 7. Sightings of marine mammals (especially whales) and seabirds, 8. Measurements of physical and chemical environmental components.

Oceanographic conditions were examined along two meridional sections of 150° and 115°E. The subtropical convergence was at 47°S along 150°E and 47.5°S along 115°E. The subantarctic front was at 49°S along 150°E and 47.5°S along 115°E. The polar front was at 56.5°S along 150°E and 55°S along 115°E. The geostrophic flow relative to 2000 dB was calculated for both sections. The maximum velocity was 18 cm $s^{-1}$ at the surface between 45° and 47.5°S along 115°E. The direction of the flow was mainly eastward for both sections.

Settling particles were collected at 1460 m and 3760 m depth in the Antarctic Ocean with sediment traps of time series type deployed at 61°30'S, 150°E. During the 42 days the concentration of silicate in the surface water decreased by 32%, whereas those of nitrate and phosphate decreased by only 4–5%. The total particulate flux (1 g $m^{-2}$ $day^{-1}$) in the Antarctic Ocean is the largest of all the world oceans. The time variation of the particulate flux at 1460 m depth almost coincided with that at 3760 m. Hydrocarbon composition was characteristic to each of the particle and sediment samples collected at 630 m, 1430 m and 3230 m. Heneicosahexaene widely occurred in diatoms and/or coccolithophores living in the surface waters.

Decomposition of chitin by the Antarctic microorganisms was investigated under

laboratory conditions. The exoskeleton of the krill was decomposed within 1 or 2 months even at a low temperature of the Antarctic Ocean, and the decomposition rate was accelerated if the chitinous exoskeleton contains some protein. In addition, the decomposition of chitin was mainly due to the characteristic community of bacteria. Vertical distribution of heterotrophic bacteria was surveyed at six stations. The total bacterial counts per m*l* of seawater in the Antarctic region ranged from $10^4$ to $10^5$, whereas the plate counts by the filter method were $10^0$ to $10^1$ in the upper 500 m layers and $10^{-1}$ to $10^0$ in the deeper water layers. More than 87% of the bacterial strains isolated from surface water of the Antarctic Ocean were orange- and yellow-pigment bacteria. Among the pigmented bacteria, Gram-negative, non-motile, orange-pigmented rods that appeared to constitute a single species belonging to *Flavobacterium-Cytophaga* predominated.

In the Southern Ocean four nannoplankton assemblages were defined, namely, subtropical, subantarctic, Antarctic and circum-Antarctic pack ice assemblages. The former three assemblages were composed mainly of calcareous nannoplankton, dominated by varieties of Coccolithophyceae. The last assemblage is dominated by a great number of siliceous microorganisms. Two kinds of phytoplankton communities were identified in the subtropical convergence at 150°E: a subantarctic diatom dominated population and a northern population with less diatom dominance. The inversion confined the subantarctic population to the shallower mixed layer which was rich in nitrate and phosphate, resulting in increased chlorophyll *a* and primary production. Phytoplankton were size-fractionated by the use of nets of differing mesh size. This enabled primary productivity to be determined for the various size fractions. The species composition of the phytoplankton was also determined. Changes were seen in the distribution and abundance of diatoms, particularly *Nitzschia*, and dinoflagellates, and these differences were related to silica concentration at different stations. Also, the vertical distribution of diatoms, dinoflagellates and other flagellates was determined.

On this cruise, zooplankton, especially chaetognaths, were used as indicators of different water masses around the subtropical convergence. *Eukrohnia hamata* accounted for more than 90% of the chaetognath numbers south of the subtropical convergence, while *Sagitta tasmanica* was most abundant north of the subtropical convergence. The vertical distribution of chaetognaths along the cruise track was examined. Salps dominated wet weight of zooplankton south of the subtropical convergence, with *Salpa thompsoni* most abundant in Antarctic waters and *Thetys vagina* dominant north of the Polar Front. The total zooplankton biomass and the abundance of four major herbivorous copepod species were compared with the corresponding data of the Discovery Investigations 50–60 years ago when the marine Antarctic ecosystem was almost near its pristine state. The total zooplankton biomass observed was well within the variation of possible sampling bias of the Discovery result, and was considered to have been almost unchanged during the past several decades. On the other hand, the abundance of three of four major herbivorous copepods is remarkably poorer with the magnitudes of $10^{-1}$ to $10^{-2}$ in more than 70% of average figures of the present study than that reported in the Discovery Investigations.

The biomass of euphausiids in the epi- and mesopelagic layers of the Southern Ocean was 0.58–16.96 g wet weight 1000 $m^{-3}$ and the total numbers of individuals was 6.8–103.1 1000 $m^{-3}$, accounting for 1.3–11.2% of the total biomass. Generally, the biomass and the total number of euphausiids in the subtropical water were the smallest in the Southern Ocean. Six genera including 18 species occurred. A total of 270 surface swarms were observed by sighting survey at 62°S and southward in the Antarctic Zone. The surface swarms of *E. superba* consisted almost exclusively of immature individuals. Geographical distribution of biomass and species, community structure, and size composition of pelagic shrimps were investigated in the upper 1000 m. The biomass ranged from 0 to 4.25 g wet weight 1000 $m^{-3}$ and in general tended to decrease southward. Twenty species occurred in the Southern Ocean and of these eight were in the Antarctic Ocean. A total of 2039 midwater fishes belonging to 19 families was caught. Of these, fishes of Families Gonostomatidae, Myctophidae and Bathylagidae comprised 95% of the total catch. Gonostomatids were by far the most numerous (72%), followed by myctophids (17%) and bathylagids (6%). The trophic levels were determined by fractionation and measurement of the concentration of the stable isotopes $^{15}N$ and $^{13}C$ in different organisms. Enrichment in the concentration of $^{15}N$ was found along the food chain.

The following gaps in the knowledge of the Southern Ocean ecosystems are the subjects for a future study: 1. Temporal and spatial relationships between phytoplankton, zooplankton and krill, 2. The life cycles and basic dynamic process of dominant members of the zooplankton community, 3. The rates of phytoplankton growth and phytoplankton community succession, 4. Studies on the dynamics of the microbial food web. There is a plan to operate new R/V HAKUHO MARU in the Antarctic Ocean to study these subjects during the summer of 1994/95.

### *2.4. Japanese Antarctic Research Expedition*

Out of the Japanese national programs for BIOMASS, JARE shared investigations in the ice-covered waters into which Japanese research vessels other than the FUJI and the SHIRASE could not penetrate. The research in the ice-covered sea was considered to be essential to have more comprehensive and deeper understanding of the Antarctic ecosystems. The BIOMASS research plan of JARE comprised onboard and shore-based studies. Onboard work consisted of routine measurement of phytoplankton biomass in the surface water along the cruise track of research vessels, observations of vertical distribution of phytoplankton and zooplankton at selected stations and the research focusing on specific topics which were done concurrently with onboard routine observations and on the fast ice around the anchorages of vessels. Shore-based studies were carried out at Syowa Station (69°00′S, 39°35′E) in the framework of a continuous three-year-round project from 1982 to 1984. Shore-based research aimed at gathering winter information of Antarctic marine ecosystem as well.

#### 2.4.1. Research onboard FUJI and SHIRASE

A routine observation of surface chlorophyll *a* distribution with physical and chemical conditions had been continued since 1965. Recognizing importance of data collected from a long-term observation along a similar route in a fixed season for the future management of marine living resources, improvement of quality of the observation was made step by step. Frequency of observations in the frontal zones was in-

creased in 1978–79 and 1979–80 to get finer scale data than before. A continuous measurement system of chlorophyll *a* was introduced in 1983–84 and improvement of the system was done in 1985–86. The position of frontal zones, its annual fluctuations and chlorophyll concentrations in relation to frontal zones were recorded. In general, chlorophyll *a* concentration was high in the south of subtropical convergence, particularly in the Antarctic convergence zone but not in the Antarctic Ocean.

Accumulated data indicated a tendency that high concentrations of chlorophyll were observed in the southbound cruises in the period from spring to summer in comparison to those in the northbound cruises in autumn. Data sets collected in some seasons showed a positive correlation between the surface chlorophyll concentrations and the integrated chlorophyll values. Relative contributions of three size fractions ($<5$ $\mu$m, 5–20 $\mu$m, $>20$ $\mu$m) to total biomass of phytoplankton were examined in 1985–86. The contribution of the fraction larger than 20 $\mu$m was higher than those of smaller ones.

To get time serial data of fluctuation of phytoplankton biomass and vertical flux of chlorophyll in the shallow layer, a mooring system equipped with a chlorophyll-measuring buoy, a current meter and a sequential multiple-sampling sediment trap was deployed in Breid Bay (70°S, 24°E) from December 28, 1985 to February 13, 1986. Continuous data of seasonal fluctuation of phytoplankton biomass (0.69 to 5.60 $\mu$g chl $l^{-1}$) with temperature data was acquired. The vertical flux of chlorophyll changed following fluctuation of chlorophyll amount in the shallow layer.

Biomass measurements of ice algae and phytoplankton, observations of vertical distribution of zooplankton and downward flux of particulate organic material were carried out in the fast ice edge zone. The biomass of ice algae was 0.38–0.80 mg $m^{-2}$ and concentrated in the bottom layer of sea ice. The biomass of phytoplankton was low (0.01–0.08 mg chl $m^{-3}$). A dense population of a copepod, *Paralabidocera antarctica* was observed beneath the sea ice. Major part of particles trapped was occupied by the fecal materials of zooplankton, in which remains of micro-algae which lived in the sea ice and water column were found.

2.4.2. Research at Syowa Station

In succession to the research in the fast ice edge, a three-year project started in the 1982 winter for studying the structure and function of ecosystems in the coastal fast ice area. To acquire basic data on the oceanographic conditions of the research area, the physical, chemical and biological observations were carried out on the routine basis at the five fixed stations for the 1982 winter, while three stations were selected out of five in 1983 and 1984. Seasonal changes of water temperature, salinity, nutrient concentration and chlorophyll *a* with phaeopigments were recorded. Chlorophyll concentration decreased in March and its low concentration continued till September. From October it began to increase following increase of solar radiation and reached a peak in the period between January and February. This pattern of seasonal change in chloropyll concentration was common to the three years but the peak figures of chlorophyll concentration varied from year to year. Heterogeneous horizontal distribution of chlorophyll concentration in the research area was observed. Seasonal succession of species composition in the phytoplankton community was examined and the measurement of productivity of the community was made in 1983.

The abundance and species composition in zooplankton communities were observed. Nine species of copepods except for Harpacticoida were identified. Numerically copepods were dominant through the 1982 winter occupying more than 84.5% of zooplankton. Individual number of copepods increased from spring to summer ($3\times10^3$ ind. $m^{-3}$). Following the autumnal decrease, it increased again with the progress of season and reached a peak ($5\times10^3$ ind. $m^{-3}$) in the midwinter season. Thereafter it decreased gradually toward early spring. *Oithona similis* and *Oncaea curvata* dominated the winter community and *Paralabidocera antarctica* did the summer community. Chaetognatha and Ostracoda appeared abundantly in winter. Survival strategy of these zooplankters in food deficient winter remained as a problem to be solved in the future. The Antarctic krill, *E. superba* were collected with a light-trap in the near-bottom layer in the dark winter and just beneath the sea ice in the light season. The observations of stomach fullness and color of stomach contents along with the above observation indicated that the krill changed their habitat from the pelagic to bentho-pelagic during dark season to subsist on detritus on the sea floor. At the same time, the lowering of oxygen consumption rate was experimentally observed. These seemed to be a way to survive in the food deficient condition.

The developmental process of ice algal communities was observed. At the initial stage of freezing of sea water, algae were brought into the sea ice by nucleation and scavenging of frazil ice. Growth of an algal community occurred two times a year, autumn and spring to summer, at the bottom of the sea ice. The bottom community occupied more than 95% of ice algal biomass (125 mg $m^{-2}$) in a given area except for the area in which an algal community developed in the lowest part of snow cover on the sea ice. It was assumed that the community in the snow layer was seeded by the algae in the ice. Strands of ice algal colonies extended from undersurface of the sea ice were regionally observed. Productivity, species composition and succession in the ice algal communities were investigated. Morphological and taxonomical studies of choanoflagellates which lived in both the sea ice and the water column were made in 1983.

Nauplii of a copepod, *Paralabidocera antarctica*, which swarmed just beneath the sea ice in summer, occurred in the bottom layer of the sea ice in March. They grew to the copepodite stage V by the beginning of summer feeding on ice algae. Then they changed their habitat to the sea water in which the enhancement of phytoplankton had begun. Nauplii and copepodites of this copepod were one of the major components of diet of a nototheniid fish, *Pagothenia borchgrevinkii* in winter.

The seasonal change of quality and quantity of suspended and sinking organic particles in the water column was investigated. The quantity of sinking particles was large and the proportion of chlorophyll to total organic carbon was high from early spring to summer compared with that in winter. The chlorophyll proportion to organic carbon in the sinking particles was higher than that in the suspended particles. It seemed that a considerable part of ice algae and/or phytoplankton was directly transferred to the sea floor. Decomposition process of suspended and sinking organic matter was experimentally investigated. Degradation of chlorophyll followed by that of phaeopigments progressed fast at $-1.5$°C in the dark. Data of time serial change of particulate organic carbon, particulate organic nitrogen and particulate

phosphorus in the experiment along with results of chlorophyll indicated that the rate of *in situ* decomposition of particulate organic matter under fast ice was comparable to that in the moderate temperature.

Observations of benthic fauna were done directly by the SCUBA diving in the shallow water and indirectly with a remote-controlled vehicle equipped with a television camera to the depth of 200 m. The biomass of epifaunal megabenthos ranged from 400 to 3000 g $m^{-2}$.

The monitoring of the Adelie penguin, *Pygoscelis adeliae* populations in the selected rookeries in the vicinity of Syowa was continued. The fluctuation of populations was remarkable. A correlation between population and ice condition was noted but detailed work on the ecology of the penguin remained as one of the future research items.

As an extension of BIOMASS, JARE begins the second phase of research in the coastal fast ice area in the 1992 winter. It consists of a time serial observation of seasonal variation of phytoplankton biomass with mooring systems, investigations on survival strategy of zooplankton and benthic animals and a paleobiological research of marine sediments. These are required to fill gaps in the present knowledge of the coastal ecosystem in the vicinity of Syowa Station. Also efforts are made to get comparable data to those of Syowa from other regions distant from Syowa. The onboard routine observations are continued, which contribute to the acquisition of data and may offer a surface truth for the satellite information on the chlorophyll distribution.

## 3. Concluding Remarks

The Japanese contribution to BIOMASS covered a wide range of research items composed of experiments of the krill ecology, studies on phytoplankton, zooplankton and micronekton including the krill in relation to the oceanographic conditions and population census of seabirds and whales with sighting. Geographical extent of Japanese BIOMASS activities ranged from 160°E to 60°W of the Southern Ocean longitudinally and from northern open water to southern ice-covered sea. Comprehensive data sets acquired accordingly seem to offer a good basis for future scientific research in the Southern Ocean.

Although there have been a considerable amount of data sets on the Antarctic marine ecosystems, further information is still required to make up the management plan of the Antarctic marine living resources. Efforts should be continued for the assessment of the krill biomass and the elucidation of life cycle of the krill and its interaction with predators. Interest of scientists in the dynamics of biological processes in such productive areas as the ice edge zone and the coastal zone has been increasing as a result of the BIOMASS research. Investigations in this field should be expanded including winter activities. Monitoring of ecosystems with the direct measurements of physical, chemical and biological parameters of oceanographic conditions and with the analyses of variation of population and behavior of such predators as seabirds, seals and whales should be continued. The direct observations of oceanographic condition and predators are necessary as the surface truth for the satellite

imagery which is effective to provide simultaneous and wide-areal information.

Recently, the Antarctic as well as the Arctic is considered as a focal point in monitoring global changes of natural environment. In particular, the role of the Southern Ocean as a sink of carbon dioxide draws attention of scientists. The data sets collected through BIOMASS activities are thought to provide a good reference for the future investigation. In this regards, research efforts initiated by the BIOMASS scientists should be continued.

## Acknowledgments

We thank the late Prof. Takahisa NEMOTO, Ocean Research Institute, University of Tokyo, for his valuable contributions to the national and international BIOMASS community. The preparation of this manuscript was completed with the help of Dr. K. WATANABE, Miss K. TAJIMA and Miss E. HATA, National Institute of Polar Research.

*(Received September 14, 1991; Revised manuscript received October 2, 1991)*

**Appendix 1. Simplified cruise tracks of the UMITAKA MARU, KAIYO MARU, HAKUHO MARU and FUJI/SHIRASE.**

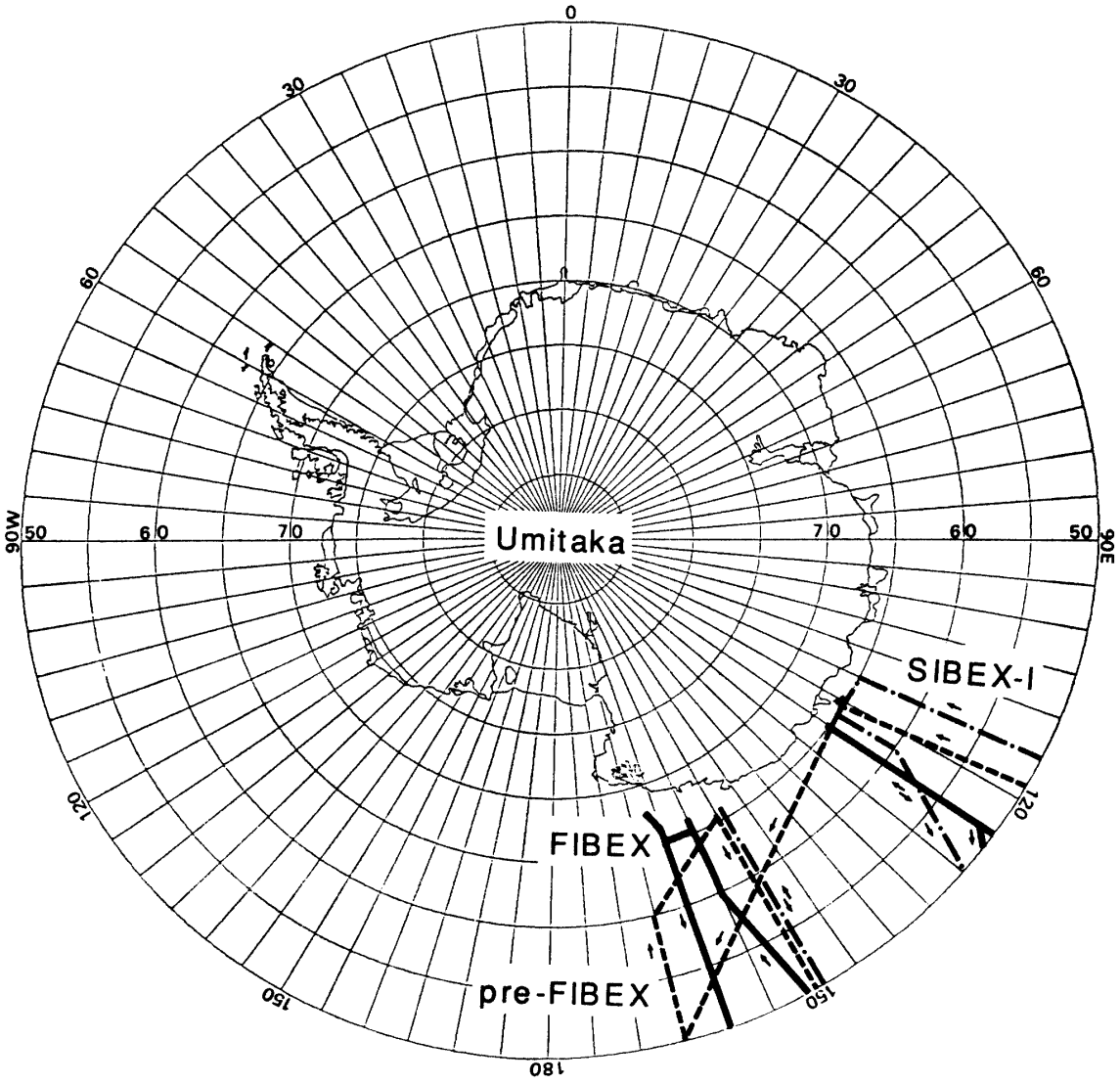


*Fig. 1. The UMITAKA MARU III conducted three cruises in conjunction with BIOMASS; Pre-FIBEX cruise (1977–78), FIBEX (1980–81) and SIBEX-I (1983–84).*

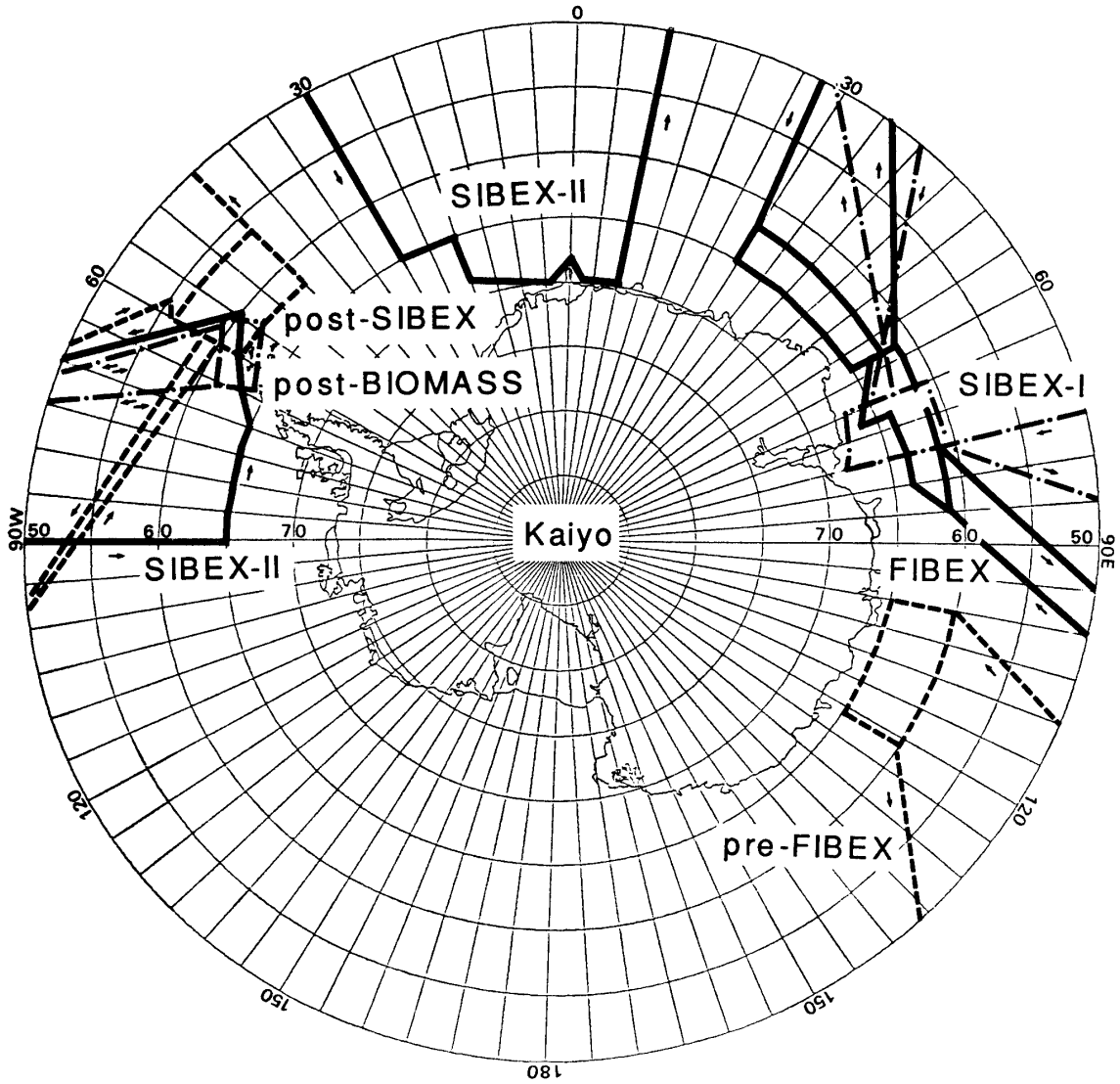


*Fig. 2. The KAIYO MARU conducted six cruises in conjunction with BIOMASS; Pre-FIBEX (1979–80), FIBEX (1980–81), SIBEX-I (1983–84), SIBEX-II (1984–85), Post-SIBEX (1987–88) and Post-BIOMASS (1990–91).*

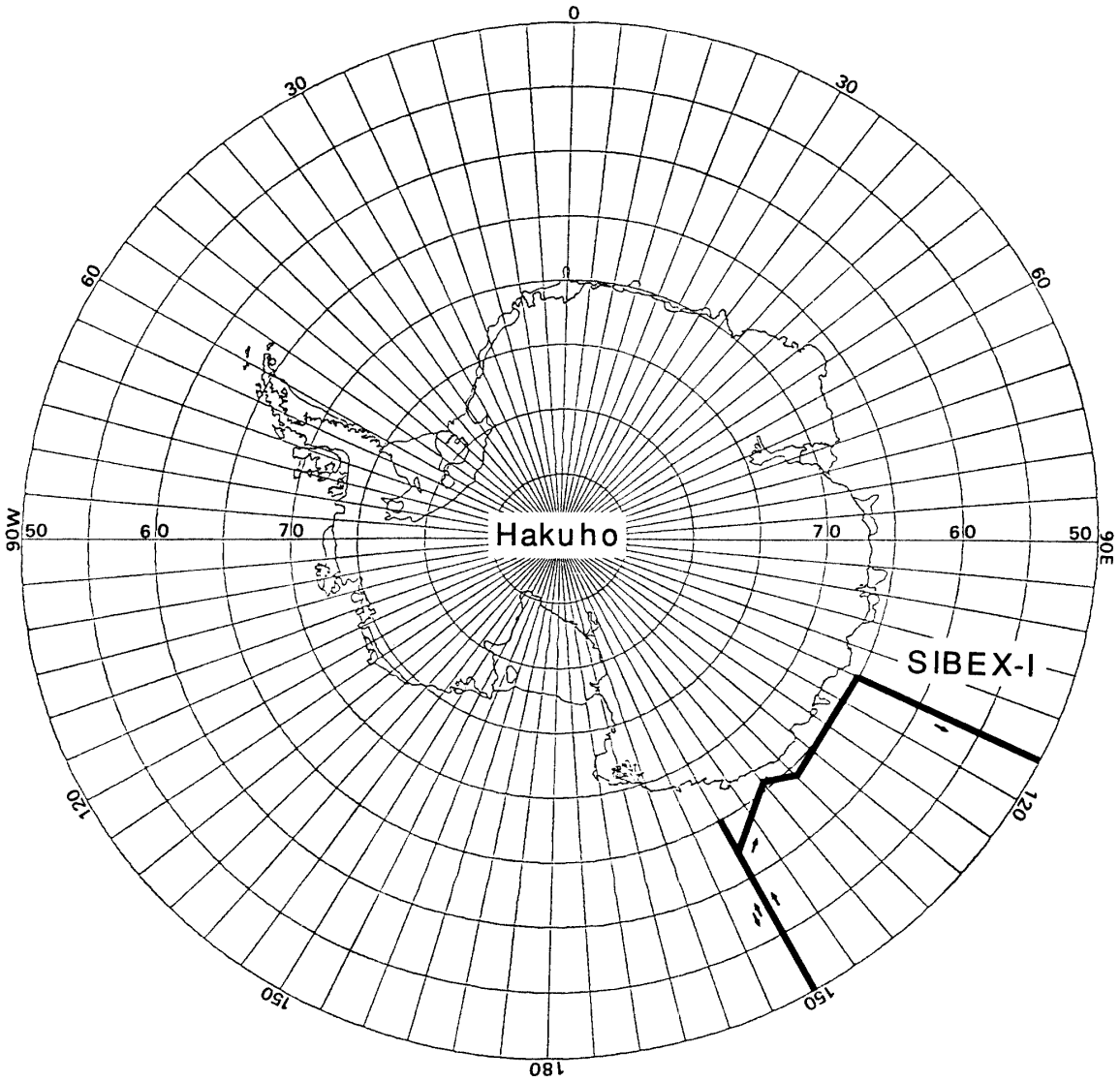


*Fig. 3. The* HAKUHO MARU *took part in SIBEX-I (1983–84) in cooperation with the* UMITAKA MARU *III.*

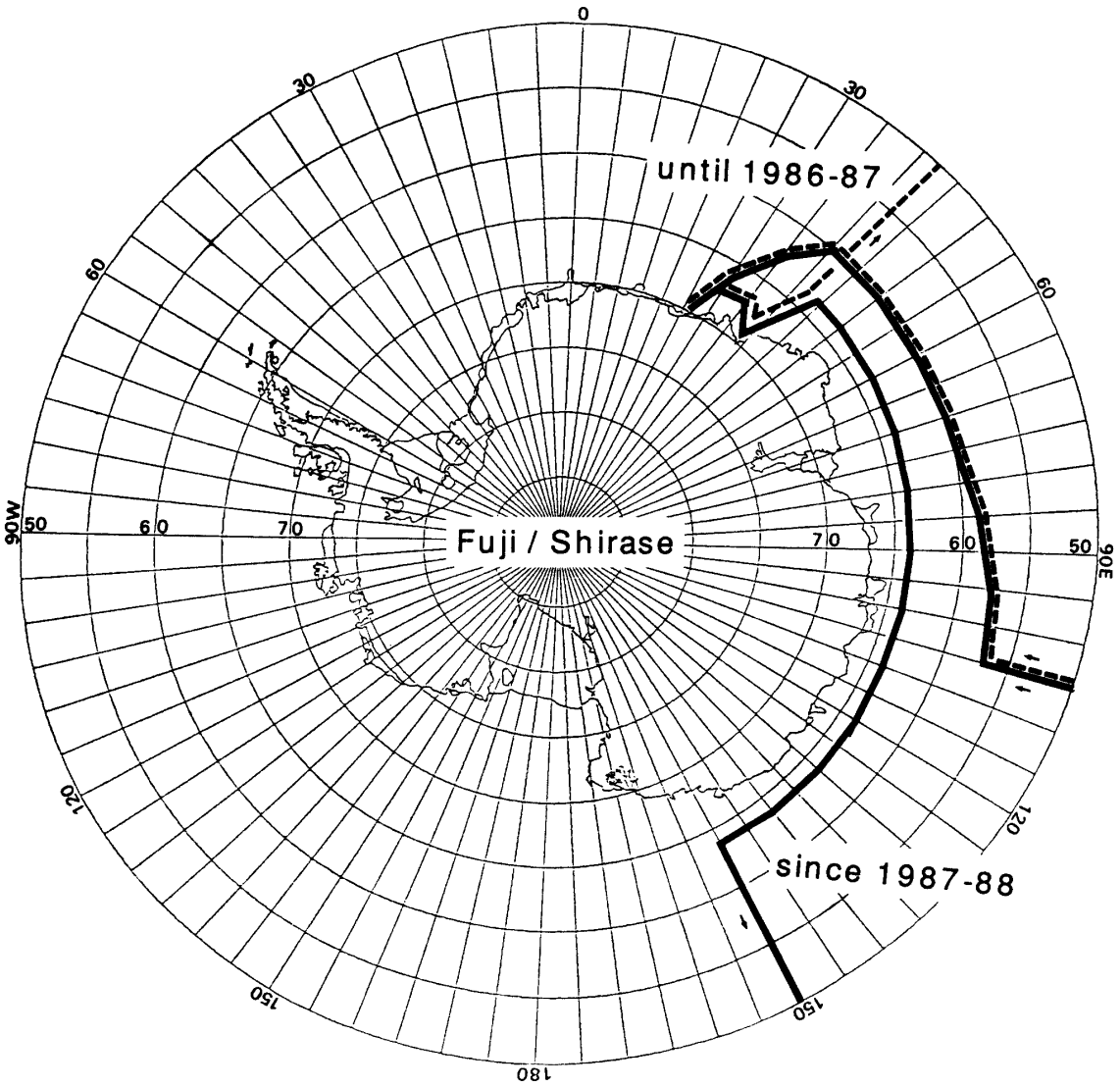


*Fig. 4. Routine observation onboard the FUJI (till 1983–84 summer) and the SHIRASE (since 1984–85 summer) were intensified in conjunction with BIOMASS. Cruise course of the SHIRASE has been changed from the 1987–88 summer onward.*

## Appendix 2. Japanese contributions to BIOMASS

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